Wearable embroidered GPS textile antenna

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Abstract-. The integration of embroidered antennas into clothing is one of the best solutions for wearable wireless communication systems, such as Global Positioning System (GPS). In this work, a wearable GPS patch antenna based on a contour fill stitch pattern is designed, manufactured and tested. The simulations have been performed by means of the full 3D electromagnetic *CST Microwave Studio 2016*, including bending effects and complex heterogeneous human model impact. The antenna operates at the GPS L1 band (1575.42 MHz) with good performance: return loss S11=-13 dB and gain G=-0.4 dBi at the operation frequency. Specific absorption rate (SAR) has been simulated and values under the electromagnetic radiation exposure limits have been obtained, with a safe margin of 24.3% in the worst case.

1. INTRODUCTION

Embroidery has been revealed as the most effective technique to implement wearable antennas. This fact is due to the availability of the manufacturing technology (industrial embroidery machines), efficient exploitation of the expensive specialized silver threads and repeatability of geometries and layouts [1]. These wearable antennas are suitable for application fields such as health monitoring, physical training, emergency rescue service and law-enforcement. In particular, the integration of flexible, lightweight and comfortable designs allow the deployment of wearable solutions for the Global Positioning System (GPS) receivers [2,3]. Since the human body is composed of a large variety of tissues types (with different dielectric and losses properties) the substrate design of the wearable antennas must include their effects. Moreover, the specific absorption rate (SAR), an established mechanism for evaluating the human body exposure to the electromagnetic radiation, must be evaluated to determine if the antennas satisfy the safety regulation limits [4].

In this work a wearable GPS patch embroidered antenna is designed, simulated and tested including the human body impact and SAR. The remainder of the paper is organised as follows. Section 2 describes the proposed embroidered antenna as well as its performance. Bending impact is also considered. In Section 3 the human body impact on the antenna parameters and the SAR simulation are assessed. Finally, section 4 summarizes the main conclusions.

2. WEARABLE ANTENNA DESIGN AND PERFORMANCE

The proposed wearable embroidered GPS patch antenna is designed and simulated by means of the full 3D electromagnetic *CST Microwave Studio 2016*, operating at the GPS L1 band (f_0=1575.42 MHz). The substrate is made by cotton with a dielectric constant εr=1.3, thickness h=0.4 mm and loss tangent tan δ=0.058. The patch metal and ground plane have been chosen as a homogeneous uniform (constant thickness t=70 µm) perfect electric conductor (PEC), for simplicity. The details of the flat antenna dimensions as well as the simulated return loss (S11) frequency behaviour in free space are depicted in Fig. 1a. The antenna area is A=115x114 mm^2 and the feed input length L_f=32 mm. A S11=-36 dB is obtained at the specified operation frequency in free space condition. In addition, the bending case with a radius for an average human arm has been considered in free space. In this case, as depicted in Fig. 1 b, the S11 is reduced to -29 dB but still achieving a good return loss condition (S11<-10 dB) with a minimum frequency shift (3.6% with regard to f_0).

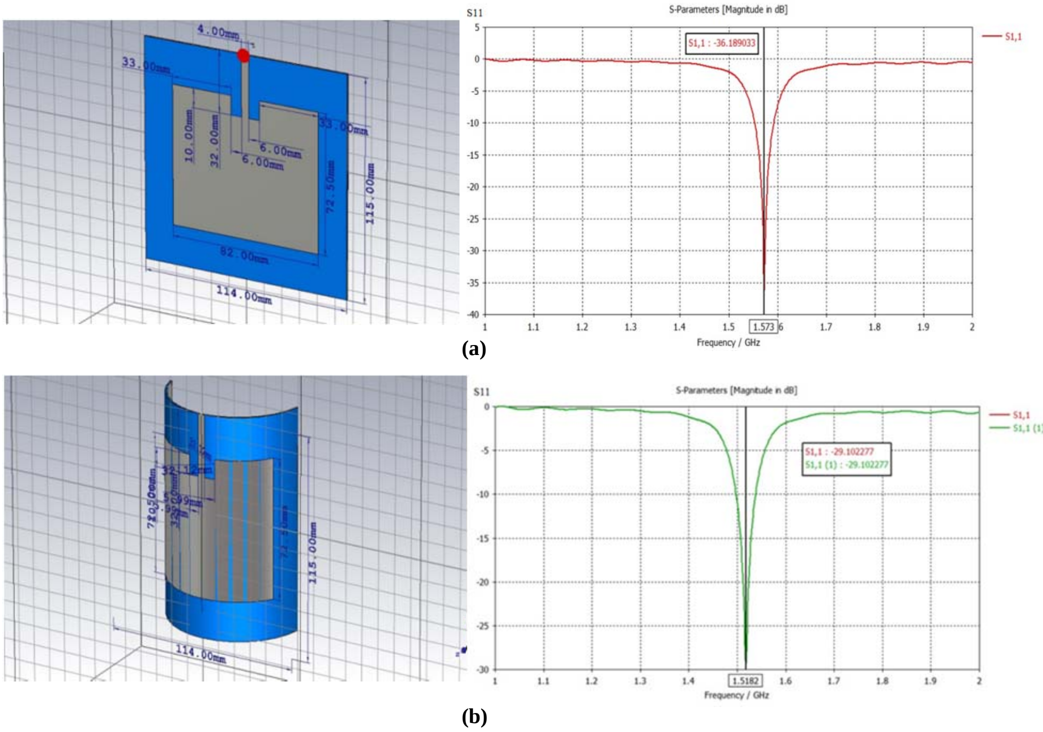


Fig. 1. (a) Designed antenna and return losses (S11) in free space. (b) Bending sample and S11 in free space.

Subsequently, the antenna layout is embroidered by means of a contour fill stitch pattern implemented with a *Singer Futura XL-550* embroidery machine. This embroidery technique consists of a curved fill stitch type following the contours of a shape creating rows of stitches across the rectangular patch shape. The number of stitch lines is constant; therefore the stitching is denser for narrower antenna geometries. The selected conductor yarn corresponds to a commercial *Shieldex 117/17 dtex 2-ply* and it is composed by 99% pure silver plated nylon yarn 140/17 dtex with a linear resistance < 30 Ω/cm. The patch antenna is based on a 2-layer cotton substrate textile and a ground plane implemented by a commercial WE-CF adhesive copper sheet. Fig. 2 shows the GPS patch antenna embroidery digitized layout by using the *Digitizer EX* software and the final manufactured prototype.

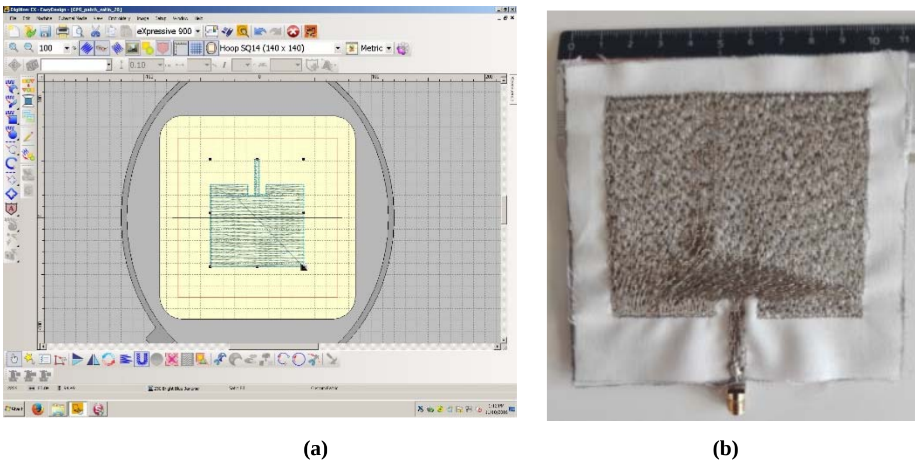


Fig. 2. (a) Screenshot of the program Digitizer EX including the antenna layout and the embroidery pattern. (b) GPS embroidered antenna patch on cotton fabric.

The experimental setup is illustrated in Fig. 3. A microwave analyser *N9916A FieldFox* operating as vector network analyser has been used to determine the corresponding S-parameters. Firstly, the S11 for return loss performance has been measured. Secondly, the S21 for the antenna realized gain measurement has been characterized by using a *R&S DST-B210* cross-polarized test antenna included in a RF diagnostic chamber *R&S DST200*. This anechoic chamber allows an interference-free testing environment (effective shielding > 110 dBm). In addition, a manual 3D positioner has been used to measure the radiation pattern gain by considering an angle step of 15 degrees.

Fig. 4 shows the experimental S11. An excellent agreement is obtained in terms of frequency operation with regards to the simulated value, whereas return loss is decreased to S11=-13 dB due to the losses and mismatch effects. Fig. 5 depicts the comparison between the simulated and experimental antenna realized gain. A similar behaviour is observed between simulation and experimental data, obtaining a measured gain G=-0.4 dBi and efficiency η=15.6% at the operation frequency. The simulated/measured normalized radiation pattern (ϕ=0º) is depicted in Fig. 6. A good agreement is also observed.

Fig. 3. Antenna measurement experimental setup.

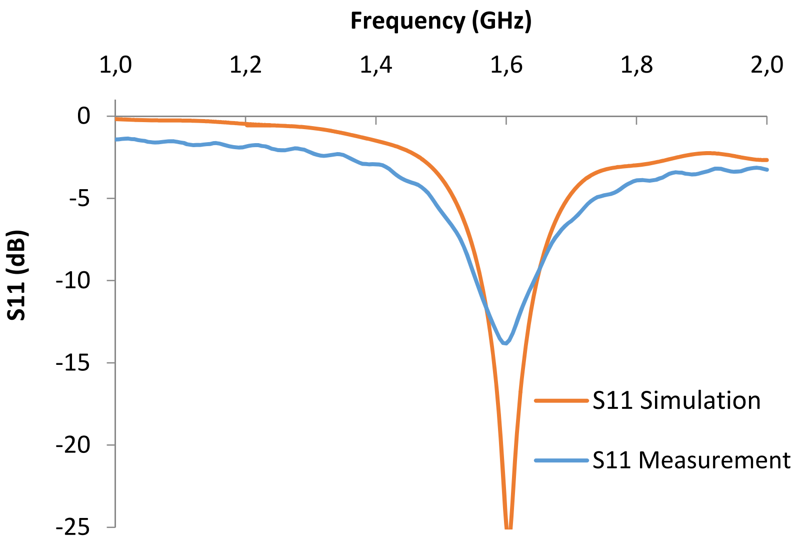


Fig. 4. Experimental and simulated GPS wearable antenna patch return losses, S11.

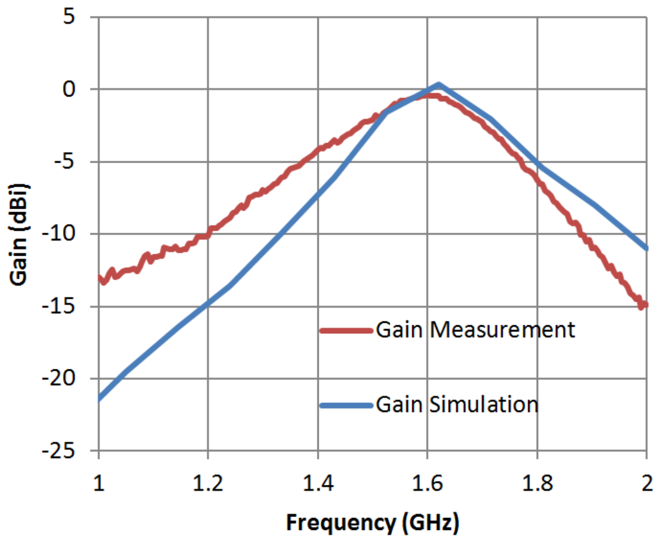


Fig. 5. Experimental and simulated GPS wearable antenna realized gain.

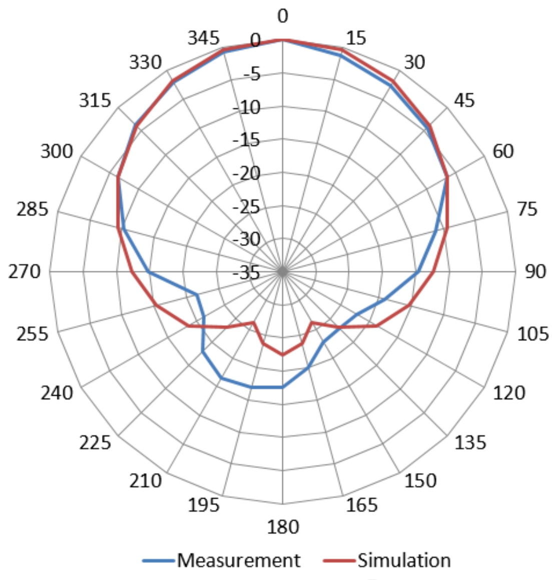


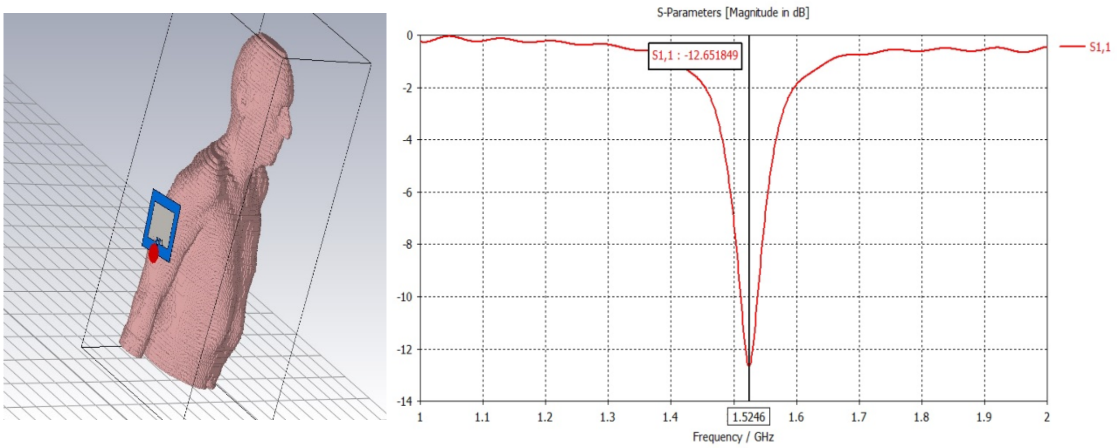
Fig. 6. Realized gain radiation pattern (normalized) @ 1.575 GHz.

3. HUMAN BODY IMPACT AND SAR EVALUATION

Figure 7a shows an adult male voxel model called Gustav (38 years old, 176 cm size, 69 Kg mass) wearing the proposed antenna in its arm. This model takes into account up to 60 human tissues and organs including their realistic non-homogeneous electric properties. This fact is essential to assess the real impact of the body on the antenna performance. In Fig. 7b the antenna return losses including the human model are depicted. As observed, acceptable values are obtained: S11=-12.6 dB and a frequency shift of 3.2% with regard to f_0.

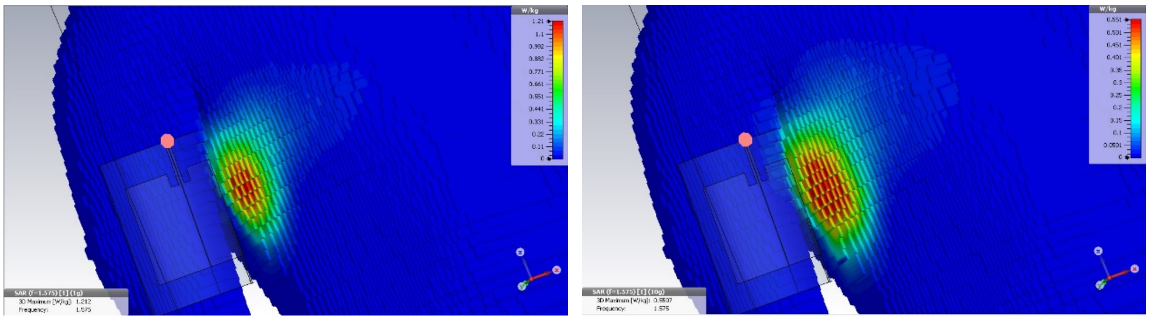
On the other hand, SAR, defined as the electromagnetic energy absorbed by the human biological tissue when exposed to the antenna radiation has been tested. The allowed general public exposure limits of SAR are: 1.6 W/Kg and 2 W/Kg averaged over 1 g and 10 g tissue, respectively. Several standard SAR simulations have been carried out by considering the standard IEEE/IEC 62704-1, according to regulators. Fig. 8 shows the 3D SAR distribution at f_0

for the bended antenna on Gustav's arm. The obtained results comply with the SAR regulation since the peak SAR values correspond to: 1.21W/Kg over 1g of tissue (24.3% lower than the limit) and 0.55<2.0 W/Kg averaged over 10g of tissue (72.5% lower than the limit).



(a) **(b)**

Fig. 7. (a) Gustav Voxel model and wearable antenna located in the arm. (b) Antenna return losses including the human model impact.



(a) **(b)**

Fig. 8. Simulated mass averaged 3D SAR at GPS frequency for the bended antenna: (b) 1 g and (c) 10 g tissue.

4. CONCLUSIONS

An embroidered GPS patch antenna has been designed and tested including the human body impact using a complex voxel model. The textile and human body effects have been studied in terms of the antenna operation frequency, radiation pattern, gain and SAR. The prototype operates at the GPS L1 band (1575.42 MHz) with good performance return loss S11=-13 dB and gain G=-0.4 dBi. SAR levels are under the legal exposure regulation limits, reaching 1.21 W/Kg over 1g and 0.55 W/Kg averaged over 10g of tissue.

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